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TIME OF COLLECTION OF ELECTRONS IN IONIZATION CHAMBERS

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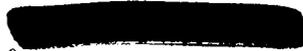
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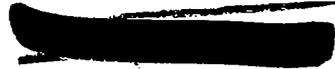
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ABSTRACT

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The drift velocity of electrons in A, CO₂, A + CO₂ mixtures, BF₃ and ECl₃ has been measured as a function of the field-pressure ratio, E/p. The drift velocity in an A + CO₂ mixture is found to be greater than in either component. This information was obtained from the observation of the rise time of the pulses produced by the collection of electrons in a parallel plate ionization chamber. A source of Po alpha particles produced the necessary ionization.



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TIME OF COLLECTION OF ELECTRONS IN IONIZATION CHAMBERS1. Introduction

The present investigation was undertaken with the purpose of checking and supplementing the existing information on the mobility of electrons in gases. The data available in the literature do not appear very consistent, the reason presumably being that, at least in the early investigations, the gases were not sufficiently pure. On the other hand, reliable information on the mobility of electrons is necessary in order to calculate the time of collection of electrons in a given ionization chamber. It is particularly important from the practical point of view to determine under what conditions this time of collection is shortest.

2. Calculation of the Mobility of Electrons in Gas Mixtures

In this section it will be shown how the mobility of electrons in a mixture of gases can be computed, if the behavior of the electrons in the pure components is known. It is, of course, assumed that no chemical reaction takes place between the gases which form the mixture. A purely phenomenological approach will be followed in order to avoid the introduction of unnecessary hypotheses. For simplicity, it will be assumed that no electron capture takes place.

Consider first a pure gas, in which electrons are liberated by some ionizing agent. In the absence of any electric field, the electrons move at random with an average energy equal to the thermal translation energy of the gas molecules $\frac{3}{2} k T$, where k is the Boltzmann constant, T the absolute temperature. At room temperature $\frac{3}{2} k T \approx 3.7 \times 10^{-2}$ ev. When an electric field E is applied, a drift velocity W is superposed to the irregular motion of the elec-

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trons and their average energy is increased above the thermal value. Let $K(3/2 k T)$ be the new value of this average energy.

The values of K and W are determined by an equilibrium condition between the energy and momentum imparted by the electric field to the electrons and the energy and momentum transferred by the electrons to the gas molecules through collisions.

For a given gas, the amount of energy transferred per unit time by the electrons to the gas molecules depends on the energy distribution of the electrons and, for a given energy distribution, it is proportional to the number of collisions per second, i.e., to the pressure p . At this point we will introduce the assumption that the energy distribution of electrons is uniquely determined by their average energy. We can then write:

$$(\text{average energy transfer per second}) = p\epsilon(K),$$

where ϵ is a function of K and represents the average energy transfer per second per electron in a gas at unit pressure.

The above assumption regarding the energy distribution of electrons is certainly not correct. It is felt, however, that it does not introduce any large source of error. On the other hand, the alternative would be actual calculation of the energy distribution of the electrons under the various conditions. One can hardly hope to carry out this calculation rigorously, both because of mathematical difficulties and lack of knowledge of the cross-sections for the various types of collisions.

Considering now the momentum transfer from electrons to gas molecules, one can easily see that the rate at which this transfer takes place in a given gas

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depends not only on the gas pressure and on the energy of the electrons, but also on the drift velocity W . Since it is zero for $W = 0$ and changes sign with W , we can consider the momentum transfer proportional to W and write

$$(\text{average momentum transfer per second}) = p W \pi (K).$$

Here π is a function of the average electrons energy K and represents the average momentum loss per second for $W = 1$ and $p = 1$ ¹⁾.

The condition that the average energy and momentum of the electrons are constant enable us now to write the following equations:

$$e E W = p \epsilon (K) \quad (1)$$

$$e E = p W \pi (K) \quad (2)$$

from which one sees that $\epsilon(K)$ and $\pi(K)$ can be calculated, for a given gas, if W and K are measured as functions of E/p .

Consider now a mixture of n gases with partial pressures p_1, p_2, \dots, p_n . The average energy transfer per second from electrons to gas molecules in the mixture is given by

$$p_1 \epsilon_1 (K) + p_2 \epsilon_2 (K) + \dots + p_n \epsilon_n (K)$$

- 1) In most treatises the rate of momentum loss is described by a mean free path for scattering at unit pressure, L . This L is defined as the average distance between collisions, and the assumption is made that, after each collision, the motion of the electrons is distributed at random. This hypothesis is not true and for our purposes unnecessary. Therefore we prefer using the concept of average momentum loss π rather than the concept of mean free path. Formally the two quantities are related by the equation $\pi = m v/L$ ($m = \text{mass}$, $v = \text{velocity}$ of the electrons). Similarly, the rate of energy loss is often described by assigning the average fractional energy λ lost per collision. This quantity is related to ϵ by the equation

$$\epsilon = \frac{v}{\lambda} \lambda \left(\frac{1}{2} m v^2 \right)$$

where $\epsilon_1(K), \epsilon_2(K) \dots \epsilon_n(K)$ are the values for the various gases and computed for the average electron energy K which prevails in the mixture. Hence Eq. (1) still holds with

$$\epsilon = (p_1/p) \epsilon_1(K) + (p_2/p) \epsilon_2(K) + \dots + (p_n/p) \epsilon_n(K) \quad (3)$$

where p is the total gas pressure.

Similarly Eq. (2) holds with

$$\pi = \left((p_1/p) \pi_1(K) + (p_2/p) \pi_2(K) + \dots + (p_n/p) \pi_n(K) \right) \quad (4)$$

where $\pi_1, \pi_2 \dots \pi_n$ are the values for π relative to the various gases. If the properties of the pure gases are given, i.e., if $\epsilon_1(K), \epsilon_2(K) \dots \epsilon_n(K); \pi_1(K), \pi_2(K) \dots \pi_n(K)$ are known as functions of K , $\epsilon(K)$ and $\pi(K)$ are known for the mixture (from Eqs. (3) and (4)). The two simultaneous Eqs. (1) and (2) can then be solved for W and determine therefore the value of the drift velocity in the mixture.

As an example, let us consider a mixture of 90 percent argon, 10 percent CO_2 . In what follows, the pressure will be measured in mm Hg and the electric field in volts/cm.

The curves marked A and CO_2 in Fig. 1 and Fig. 2 represent ϵ/e and π/e for A and for CO_2 respectively. These curves were calculated from the data in the book by Healey and Reed; "Behaviour of Slow Electrons in Gases". The curves marked .9 A + .1 CO_2 in the same figures give the values of

$$(\epsilon/e) = 0.9 (\epsilon/e)_A + 0.1 (\epsilon/e)_{\text{CO}_2} \quad \text{and}$$

$$(\pi/e) = 0.9 (\pi/e)_A + 0.1 (\pi/e)_{\text{CO}_2}$$

for the mixture. The product of these two quantities, according to Eqs. (1) and (2), gives $(E/p)^2$ as a function of K for the mixture. For example, one finds $E/p = 1$ for $K = 27$, which means that $27 (\frac{3}{2} k T)$ is the energy of electrons in the mixture when $E/p = 1$. For $K = 27$, Fig. 2 gives $\pi/e = 1.35 \times 10^{-7}$ from which one calculates the drift velocity at $E/p = 1$

$$W = (E/p)/(\pi/e) = 7.4 \times 10^6 \text{ cm/sec.}$$

It is interesting to note that this velocity is considerably higher than the drift velocities in either pure argon or pure CO_2 , which are (again for $E/p = 1$) 6×10^5 and 5.5×10^6 respectively. The physical reason for this fact can be easily understood from an analysis of the behavior of electrons in the two gases. Fig. 1 shows that the energy loss of electrons in argon is very small until K reaches a value of about 270 (which corresponds to 10 ev) and then starts rising abruptly, while in CO_2 the energy loss is already large for small values of K and rises steadily with increasing K . This is due to the fact that in argon no inelastic collisions occur unless the electrons have an energy larger than the first excitation level, which is of the order of 10 ev. In CO_2 however inelastic collisions occur very frequently already for small electron energies, because of the large number of low excitation levels of the CO_2 molecule. It follows that in pure argon even with moderate values of E/p , the average electron energy is quite high, i.e., of the order of 10 ev. Addition of 10 percent CO_2 cuts down this energy very considerably (to about 1 volt with $E/p = 1$).

On the other hand, Fig. 2 shows that the average momentum loss in argon decreases rapidly with decreasing electron energy. This is essentially due to the decrease of the elastic scattering cross-section with energy, known as the Ramsauer

effect. The momentum loss in the mixture of 0.9 A + 0.1 CO₂ is not very different from the momentum loss in pure A, on account of the small proportion of CO₂. Hence one can say that the main effect of a small addition of CO₂ to A is to bring the average electron energy from a high value, for which π is large, to a low value, for which π is small. This increases the electron mobility because this quantity is inversely proportional to π .

As compared with pure CO₂, the drift velocity in the mixture is larger because the CO₂ is more diluted. In other words the drift velocity that one obtains in one atmosphere of 0.9 A plus 0.1 CO₂, with a given electric field, is not much smaller than the mobility that one would obtain with the same field in 0.1 atmospheres of CO₂ alone.

3. Earlier Measurements of the Drift Velocity W and the Average Energy of Agitation K

Most of the early measurements of the drift velocity W have been made by a method developed originally by Townsend. In this method electrons produced either thermionically or photo-electrically are allowed to move in a uniform electric field between two parallel plates. The lower plate has three collecting electrodes. A uniform magnetic field H is applied in a direction normal to that of the electric field E. By measurement of the angular deflection θ of the electron beam, Townsend was able to calculate the drift, velocity W by means of the relation

$$\tan \theta = (H/W/E).$$

K may also be measured by Townsend's method in the following manner. In the absence of the magnetic field the electrons will drift in the direction of the



electric field and also will diffuse out of the beam in a direction normal to the electric field. Therefore a certain fraction of the total current will reach the outer collecting electrodes. The ratio of the current collected by the outer to that collected by the central electrode is determined for various values of E/p and then K can be determined from a solution of the diffusion equation.

Bailey and Healey have used methods similar to that of Townsend. Most of the data given in the book, "The Behaviour of Slow Electrons in Gases", have been measured in this manner.

Bradbury and Nielson developed an electron shutter, originally invented by Loeb for a different purpose. This shutter consists of a grid of fine parallel wires separated by a distance of 1 mm and insulated from one another. Alternate wires are connected to the opposite terminals of an oscillator operating at frequencies of 10^4 to 10^7 cycles per second.

A potential difference of some tens of volts applied to such a pair of wires makes them able to catch all the free electrons in their neighborhood or between them. Such a grid is transparent to electrons for a very short time only when it is passing through zero potential difference. In practice two such shutters are used, and from a knowledge of their separation and the frequency of the oscillator the time required for an electron to pass between the two shutters can be determined.

4. The Direct Measurement of the Electron Collection Time in an Ionization Chamber

The present investigation was undertaken for the following reasons. Much of the existing information on electron drift velocities is neither very accurate nor consistent. In addition, many of the gases used in ion chambers have not been investigated and no measurements of the collection time in an A-CO₂ mixture have



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been reported. Finally, a more direct method of determining the shape of the pulse produced by an ionization chamber is desirable.

A diagram of the parallel plate ionization chamber and gas purifier is shown in Fig. 3. The high voltage electrode A was a circular steel disk 2" in diameter supported by a rod through a Kovar porcelain insulator. The separation between the electrode A and the collector C was 16 mm. A Po alpha-particle source at S produced a thin beam indicated by the dotted line. Gas was admitted to the chamber through a needle valve equipped with a metal bellows instead of a packing gland.

The gas purifier consisted of a steel tube containing several grams of calcium pellets. A small quantity of glass wool at either end of the tube prevented calcium powder from entering the ion chamber. The purifier could be heated to 350° C by means of a coil wound on a layer of asbestos paper around the steel tube. The gas filling procedure consisted in evacuating the system, outgassing the purifier at 350° C for several hours and finally torching the ion chamber to a temperature of about 150° C. The gas was admitted to the system after it had cooled to room temperature.

A block diagram of the amplifiers and sweep circuits used for measuring the electron collection time is shown in Fig. 4. The low frequency out off of the amplifier was determined by a time constant of 20 microseconds in the grid circuit of the first tube of the main amplifier. The output of the main amplifier was connected to a one microsecond delay line and also to a pulse discriminator. The discriminator triggered a sweep circuit each time a pulse was recorded. Since a time of about 0.2 μ sec was required to start the sweeps the one microsecond delay caused the pulses to appear about 0.8 μ sec from the beginning of the sweep. Tests

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with a pulse generator showed that the delay line produced negligible distortion in pulses having a rise time greater than 0.1 microsecond. The rise time of the entire amplifier was about 0.2 microsecond and the gain was 3.5×10^4 .

Argon

The argon was obtained from an Ohio Chemical Co. tank and was 99 percent pure. After the chamber had been filled to the desired pressure the purifier was operated at 300°C for an hour. Measurements of collection time and pulse height were taken with the purifier at room temperature. Pressures of 840, 1100, 1050 and 2080 mm Hg were used. Within the experimental errors, W was found to be a function of E/p , as anticipated.

The data for electron collection in argon is plotted in Fig. 5. Curve A represents the drift velocity as a function of E/p with the α particles parallel to the condenser plates and curve B represents the drift velocity measured in another chamber with the α particle beam perpendicular to the condenser plates. Curves C and D, respectively, represent the data of Townsend and Bailey and of Bradbury and Nielson for the drift velocity. The pulse height as a function of E/p is given in curve E.

CO₂

The CO₂ gas was obtained from an Ohio Chemical Co. cylinder and was introduced into the chamber without further purification. The pressure used was 890 mm Hg. The pulse height observed was much smaller than for argon under the same conditions. However, after the purifier containing calcium had been heated for an hour at 140°C the pulse height increased to a value about 0.8 that observed for argon.

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Curve A of Fig. 6 represents our values for the drift velocity in CO₂ and curve B represents the data of M. F. Skinker. Curve C gives the pulse height as a function of E/p , according to our measurements.

A + CO₂

In order to measure the drift velocity in a mixture of A and CO₂ the ion chamber was filled with A to a pressure of 840 mm Hg and then the gas was purified as before. Sufficient CO₂ was added to make the mixture and then the purifier was heated to 140° C in order to purify the CO₂.

Curves A and B of Fig. 7 represent the drift velocity in .9 A + .1 CO₂ and .95 A + .05 CO₂. Curve C was calculated for a mixture of .9 A + .1 CO₂ by the method described in section 2.

BF₃

The BF₃ gas was prepared by Horace Russell from two different sources. Gas was taken from an Ohio Chemical Co. tank and passed through a tube containing NaF and condensed in a trap cooled with liquid nitrogen. The gas was pumped and melted twice in this trap and no non-condensable gas was present at the last freezing. The second source of BF₃ was the compound C₆H₅N₂BF₄, which was carefully dried and thermally decomposed in a vacuum. Analysis by the HCN method indicated that the gas was from 99.7→99.8 percent pure.

The drift velocity as a function of E/p for four samples of BF₃ is given in Fig. 8 and the pulse height as a function of E/p is given in Fig. 9 where the pressures used are also indicated.

The drift velocities observed in the four samples agree reasonably well. However, there is considerable difference in the values of the pulse height ob-

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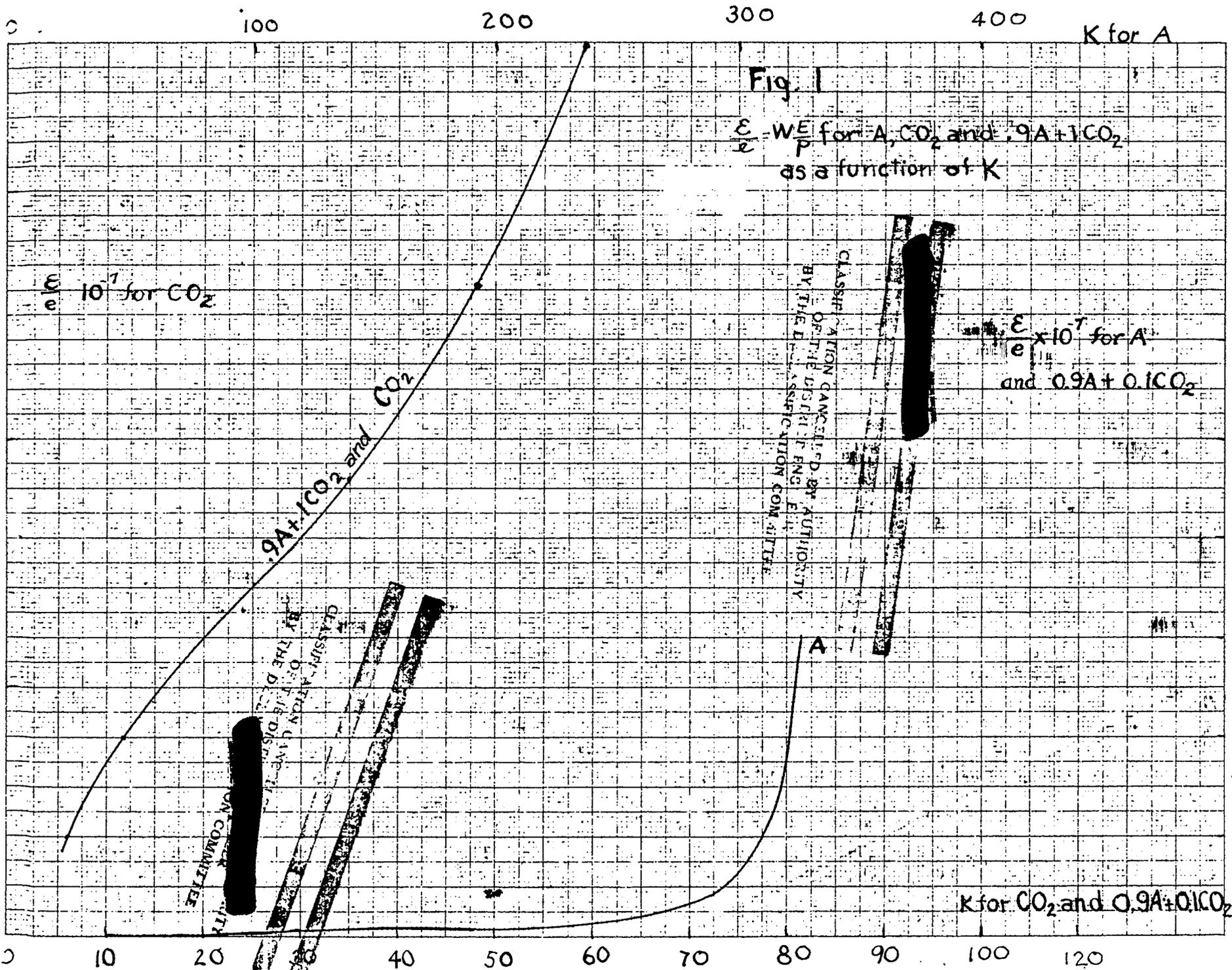
served at a given value of E/p in the four samples of BF_3 . This indicates the presence of some impurity in the BF_3 which causes appreciable electron capture.

BCl_3

BCl_3 was obtained from Columbia University in a sealed ampoule and was guaranteed to be 99.5 percent pure. The ion chamber was evacuated, torched and filled to a pressure of 381 mm of Hg. Several days later the BCl_3 was removed from the ion chamber frozen and pumped and 1/2 sample distilled from CO_2 ice trap and discarded. The remainder was returned to the ion chamber. The purpose was to remove any HCl which may have been formed by hydrolysis. The final pressure was 191.5 mm of Hg. No electron pulses could be observed for either of the fillings, which indicates large electron capture.

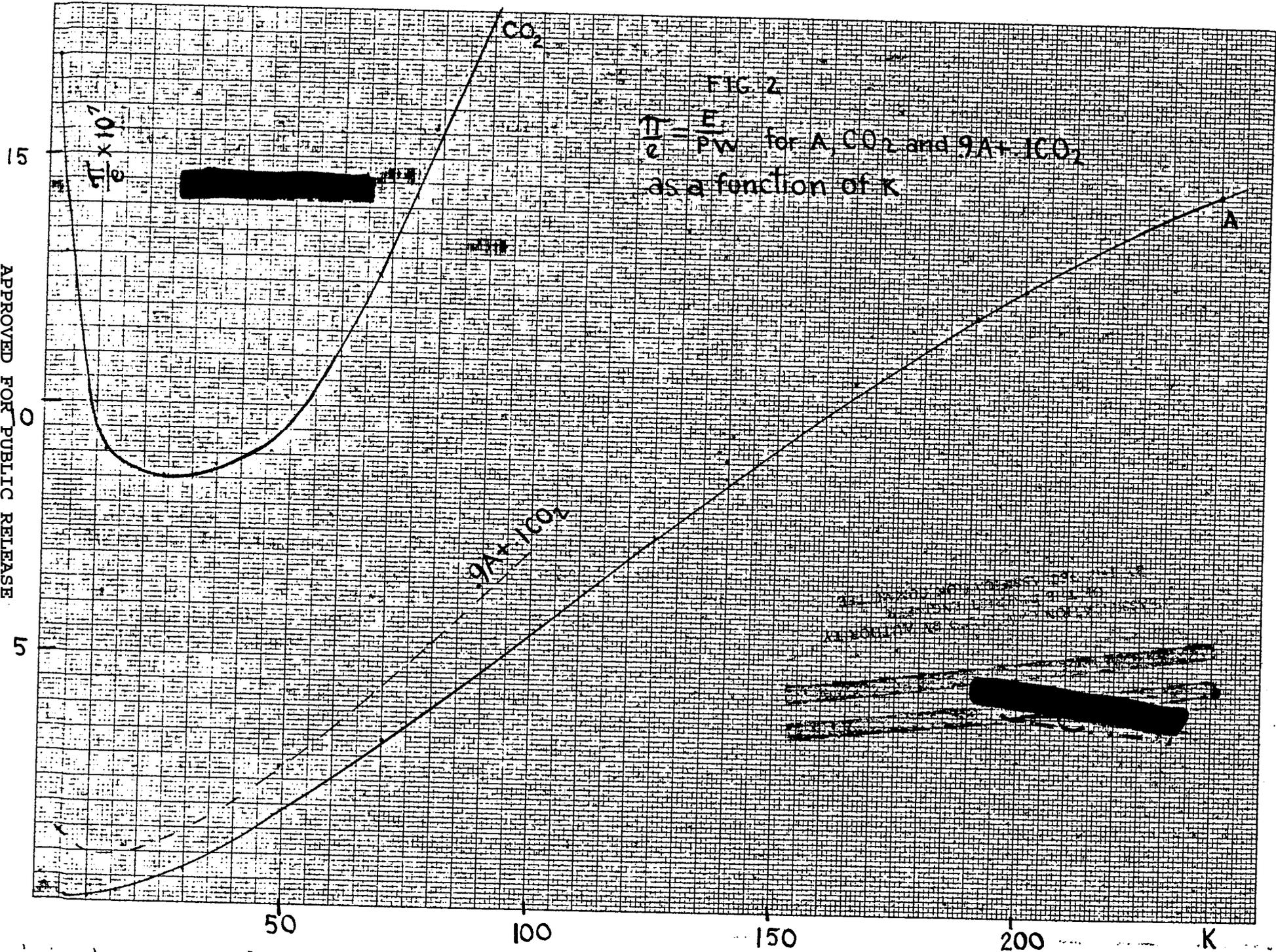
Conclusion

Our measurements give, for the drift velocity in argon and CO_2 , values of the same order of magnitude as the published data. The drift velocity in mixtures of argon and CO_2 was found to be considerably larger than in either component, in qualitative agreement with the theory. Large drift velocities were found in BF_3 . We wish to emphasize that these are to be considered only as preliminary results and that further measurements are desirable.



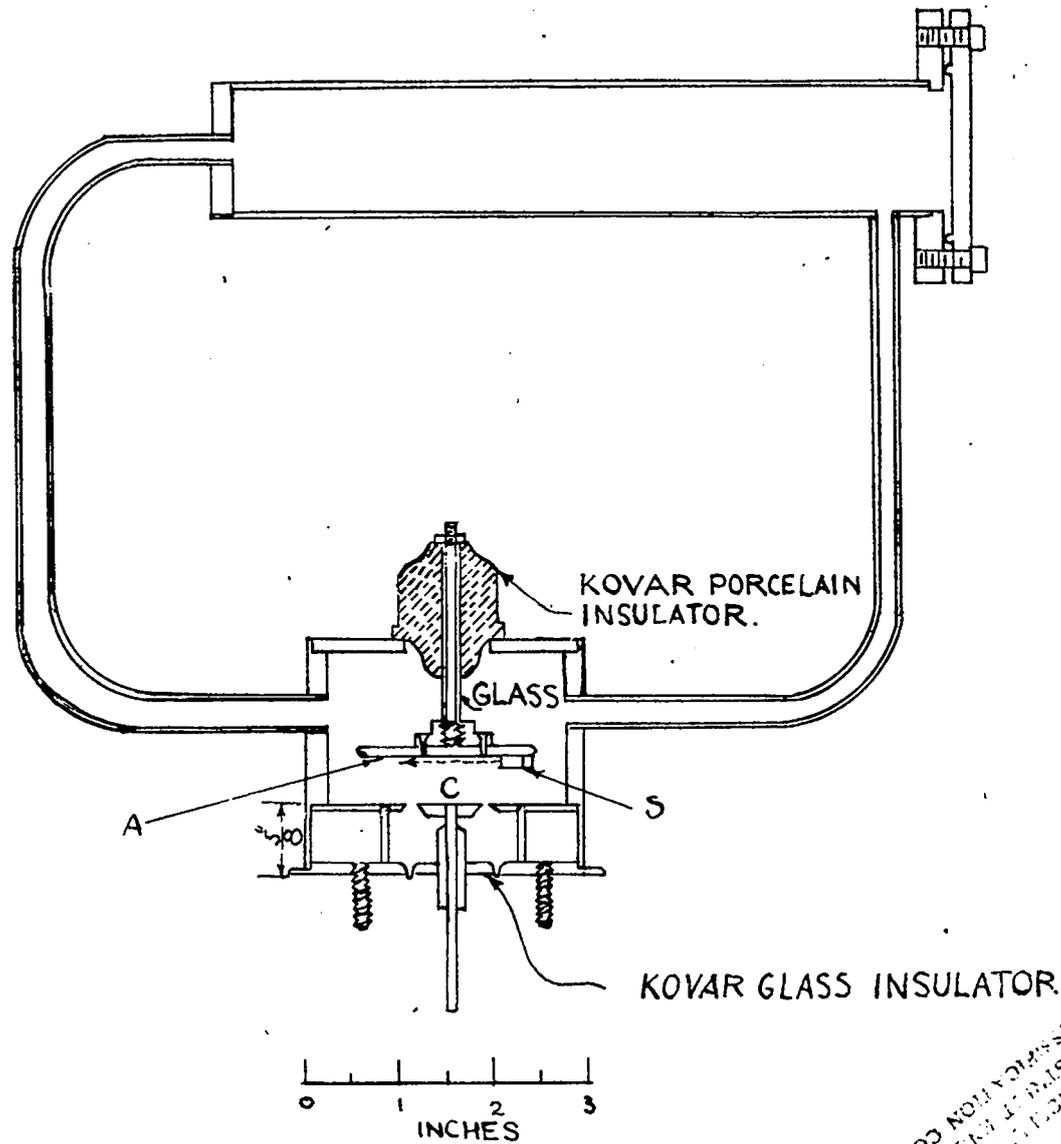
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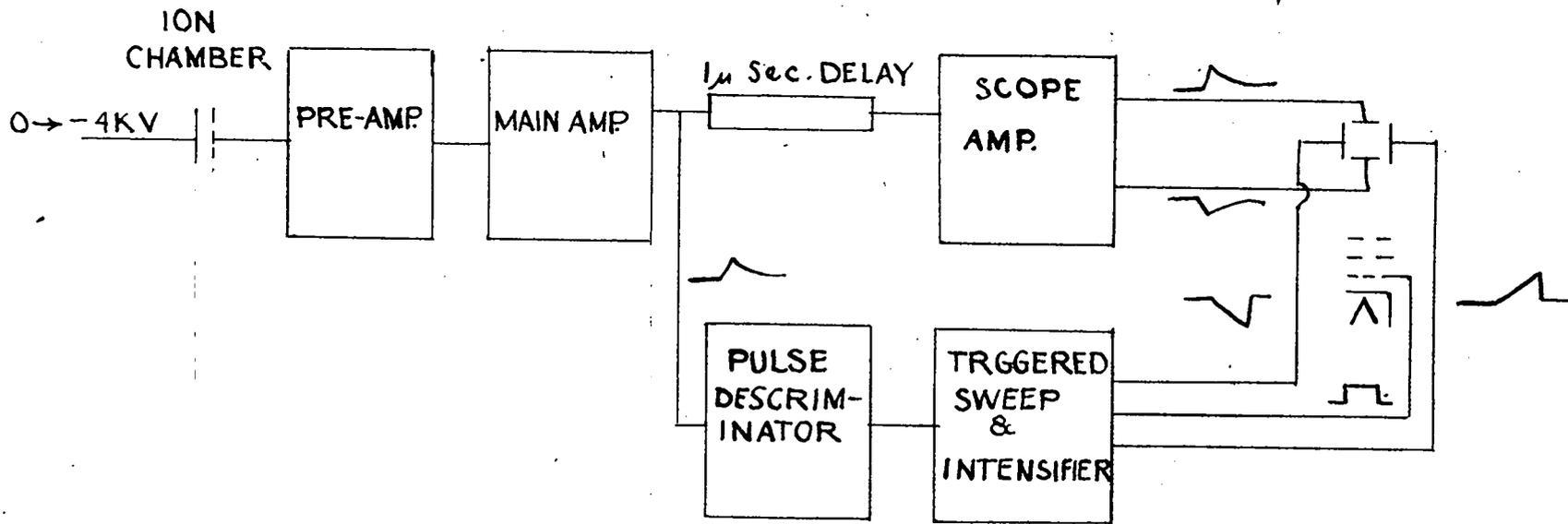
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FIG. 3

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BLOCK DIAGRAM OF AMPLIFIERS
AND SWEEP CIRCUITS USED FOR MEASURING
THE ELECTRON COLLECTION TIME IN AN
IONIZATION CHAMBER.

FIG. 4

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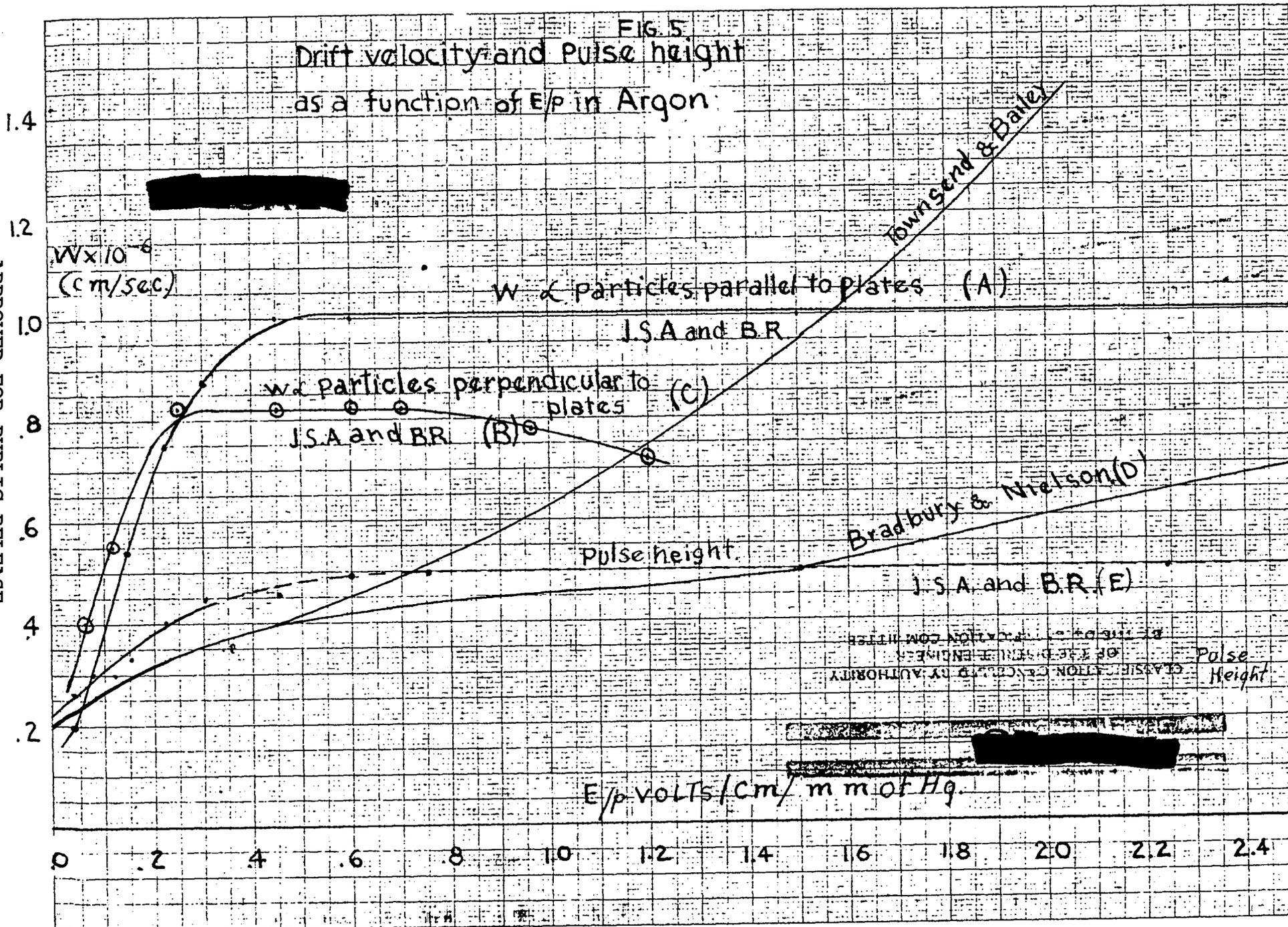
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FIG. 5
Drift velocity and Pulse height
as a function of E/p in Argon

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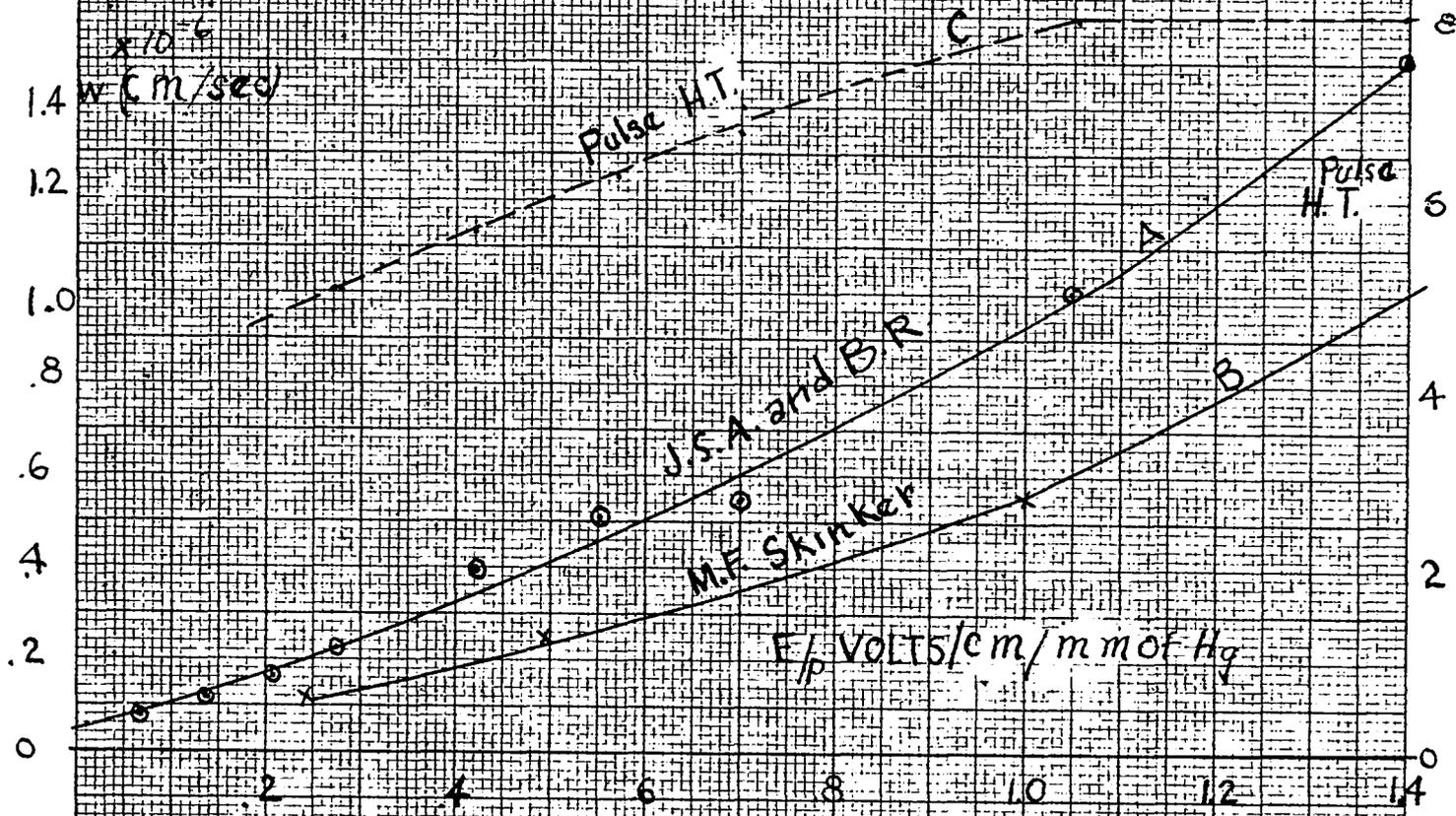


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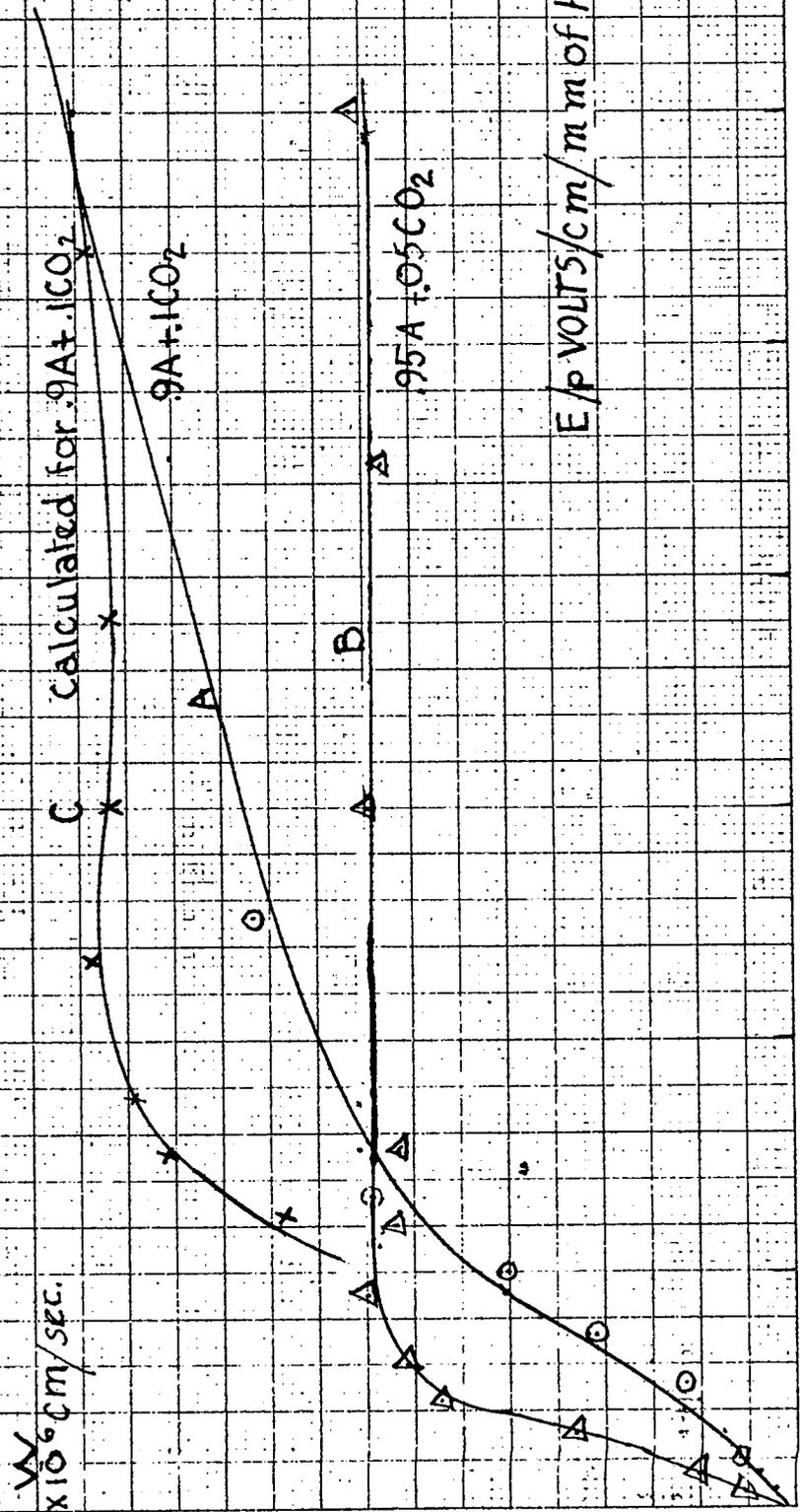
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Fig. 6
Drift velocity and pulse height
as a function of E/p in CO_2



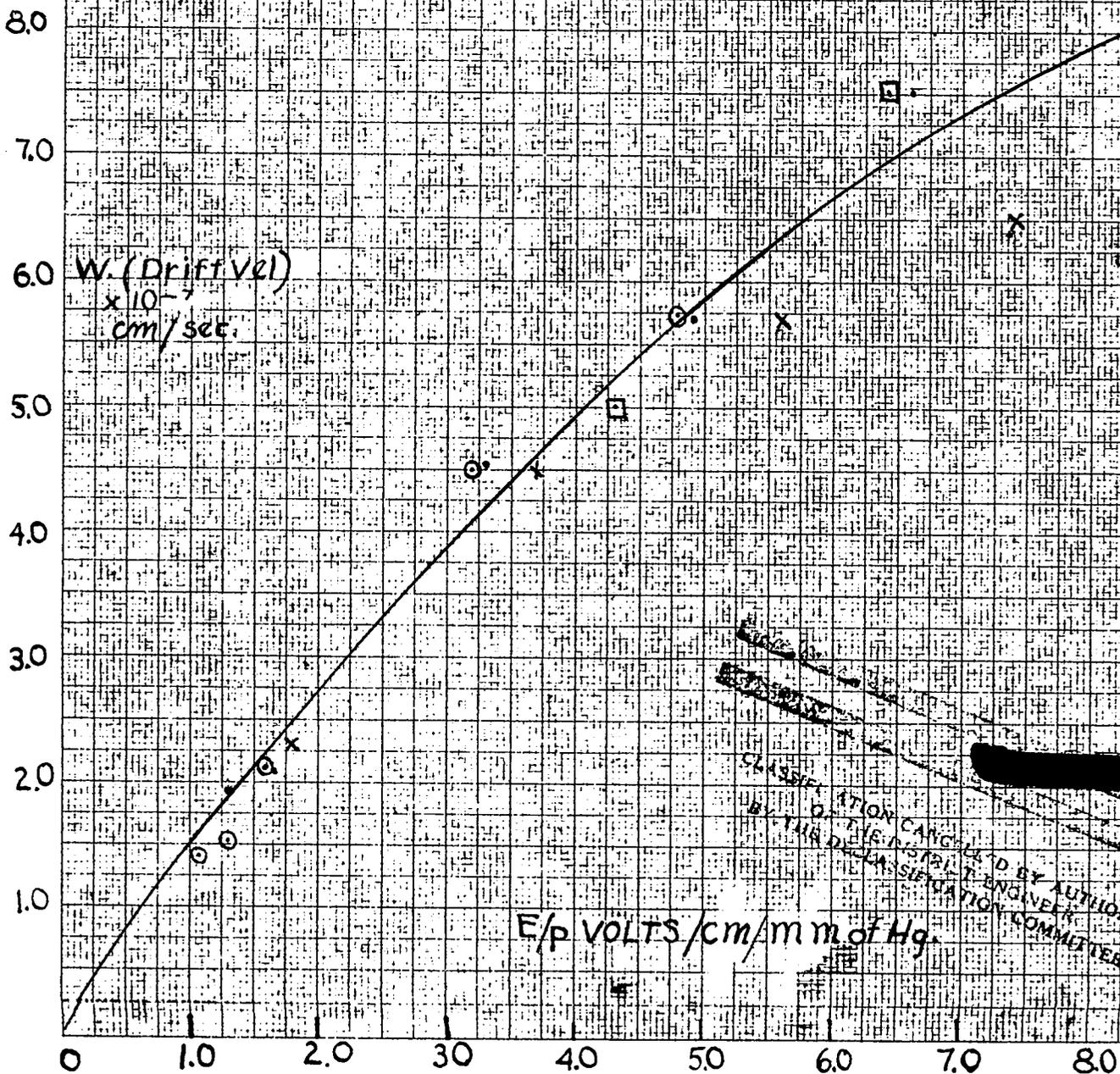
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Fig 7
Drift velocity as a function of E/p
in mixtures of A and CO_2



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FIG. 8
 Electron collection in BF_3
 Drift velocity as a function of E/p
 • BF_3 from $C_6H_5N_2BF_4$ $P=379$ mm of Hg
 ○ BF_3 from Tank $P=388$ mm of Hg
 × BF_3 from $C_6H_5N_2BF_4$ $P=339$ mm of Hg
 □ BF_3 from Tank $P=294$ mm Hg



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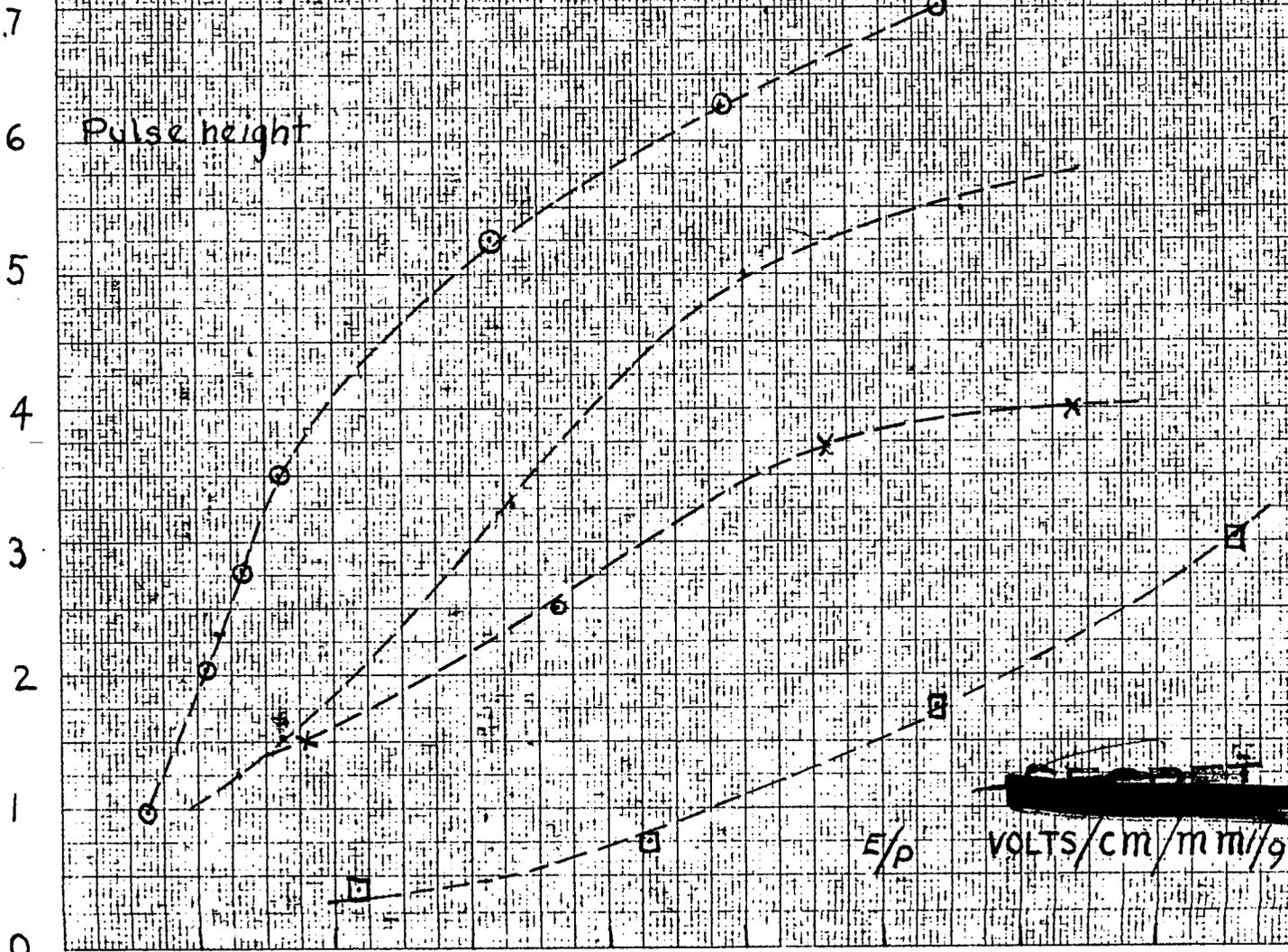
Fig. 9
ELECTRON COLLECTION IN BF_3
Pulse height as a function of E/p

• BF_3 from $C_6H_5N_2BF_4$
x " " " "
○ BF_3 from Tank
□ " " " "

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Pulse height

E/p VOLTS/cm/mm/g



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